

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
<p>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>					
1. REPORT DATE (DD-MM-YYYY) 11/15/2016		2. REPORT TYPE Final		3. DATES COVERED (From - To) 6/15/2015 through 6/31/2016	
4. TITLE AND SUBTITLE Acquisition of Ice-Tethered Profilers with Velocity (ITP-V) Instruments for Future Arctic Studies				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER N00014-15-1-2892	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Toole, John M. Krishfield, Richard A. Cole, Sylvia T.				5d. PROJECT NUMBER WHOI # 13289200	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Woods Hole Oceanographic Institution 266 Woods Hole RD Woods Hole, MA 02543-1536 USA				8. PERFORMING ORGANIZATION REPORT NUMBER Final	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The objective of this DURIP award was to build three Ice-Tethered Profiler with Velocity (ITP-V) systems for deployment in support of future Navy scientific investigations of the Arctic Ocean. This work was accomplished. To the standard ITP instrument that measures sea water temperature and salinity versus depth, the ITP-V adds a multi-axis acoustic-travel-time current meter and associated attitude/motion measuring unit to make direct, 3-D observations of ocean flow. The three new systems are scheduled to be deployed to support the ONR Stratified Ocean Dynamics of the Arctic DRI.					
15. SUBJECT TERMS Arctic Ocean, Ice-tethered Profilers					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON John M. Toole
a. REPORT Unlimited Unclassified	b. ABSTRACT Unlimited Unclassified	c. THIS PAGE Unlimited Unclassified			19b. TELEPHONE NUMBER (Include area code) 508-289-2531



## INSTRUCTIONS FOR COMPLETING SF 298

**1. REPORT DATE.** Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

**2. REPORT TYPE.** State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

**3. DATE COVERED.** Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

**4. TITLE.** Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

**5a. CONTRACT NUMBER.** Enter all contract numbers as they appear in the report, e.g. F33315-86-C-5169.

**5b. GRANT NUMBER.** Enter all grant numbers as they appear in the report. e.g. AFOSR-82-1234.

**5c. PROGRAM ELEMENT NUMBER.** Enter all program element numbers as they appear in the report, e.g. 61101A.

**5e. TASK NUMBER.** Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

**5f. WORK UNIT NUMBER.** Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

**6. AUTHOR(S).** Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES).** Self-explanatory.

**8. PERFORMING ORGANIZATION REPORT NUMBER.** Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES).** Enter the name and address of the organization(s) financially responsible for and monitoring the work.

**10. SPONSOR/MONITOR'S ACRONYM(S).** Enter, if available, e.g. BRL, ARDEC, NADC.

**11. SPONSOR/MONITOR'S REPORT NUMBER(S).** Enter report number as assigned by the sponsoring/monitoring agency, if available, e.g. BRL-TR-829; -215.

**12. DISTRIBUTION/AVAILABILITY STATEMENT.** Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

**13. SUPPLEMENTARY NOTES.** Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

**14. ABSTRACT.** A brief (approximately 200 words) factual summary of the most significant information.

**15. SUBJECT TERMS.** Key words or phrases identifying major concepts in the report.

**16. SECURITY CLASSIFICATION.** Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

**17. LIMITATION OF ABSTRACT.** This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

## **Acquisition of Ice-Tethered Profilers with Velocity (ITP-V) Instruments for Future Arctic Studies**

John M. Toole

MS 21/354a Clark Laboratory, WHOI Woods Hole, MA 02543  
phone: (508) 289-2531 fax: (508) 457-2181 email: jtoole@whoi.edu

Richard A. Krishfield

MS 21/128 Clark Laboratory, WHOI Woods Hole, MA 02543  
phone: (508) 289-2849 fax: (508) 457-2181 email: rkrishfield@whoi.edu

Sylvia T. Cole

MS 21/354c Clark Laboratory, WHOI Woods Hole, MA 02543  
phone: (508) 289-3805 fax: (508) 457-2181 email: scole@whoi.edu

Award Number: N00014-15-1-2892

<http://www.whoi.edu/itp>

### **LONG-TERM GOALS**

The PI group seeks to observe the upper Arctic Ocean using autonomous instrumentation and build understanding of the physical processes controlling the evolving thermohaline stratification, the ocean currents and air-ice-sea interactions on time scales of minutes to seasonal and longer.

### **OBJECTIVES**

Build three Ice-Tethered Profiler with Velocity (ITP-V) systems for deployment in support of future Navy scientific investigations of the Arctic Ocean.

### **APPROACH**

The instrument design and construction is based on prior developmental work and field testing of prototypes, and the subsequent successful use of 5 operational ITP-V systems during the Marginal Ice Zone DRI program. The ITP-V is assembled from subsystems constructed in house as well as components from commercial vendors. Key personnel at WHOI involved in the construction and validation testing of ITP-V systems beyond the PIs include J. O'Brien, F. Thwaites, J. Kemp and C. Marquette.

The ITP-V is a variant of the ITP system that has contributed to sustained observations of the Arctic Ocean below sea ice since 2004. The ITP concept is, in short, Argo of the Arctic - a play on the international program maintaining an array of profiling floats throughout the temperate oceans. Briefly, the ITP system consists of three main components: a buoyant surface instrument package that typically sits atop an ice floe, a weighted, wire-rope tether suspended from the surface package, and an instrumented underwater unit that travels up and down the wire tether (Figure 1; Krishfield et al., 2008; Toole et al., 2011). The current design of the ITP surface



expression is a conical-shaped buoy that houses a controller, inductive modem electronics, a GPS receiver, and an Iridium satellite phone with associated antennae and batteries within a watertight aluminum housing capped by an ultra-high-molecular-weight polyethylene dome. The electronics case sits within a foam body designed to provide buoyancy for the plastic-jacketed wire rope tether and end weight should the ice fracture or melt, and to provide modest protection in the event of ice ridging. The profiler unit (much like an Argo float in shape and size) mounts on the tether and cycles vertically along it. Via an inductive modem, raw sensor and associated engineering data files are relayed from the underwater vehicle to the surface buoy at the completion of each one-way profile, which then transmits them by satellite to a logger computer at WHOI. The ITP-V instruments add a multi-axis acoustic-travel-time current meter and associated attitude/motion measuring unit to the standard ITP sensor suite to make direct, 3-D observations of ocean flow (Figure 2, 3; Thwaites and Krishfield, 2013; Cole et al., 2014; 2015).

## **TASKS COMPLETED**

The 3 ITP-V systems were fully built/assembled by early August, 2016 and spin tests were performed. These tests involve logging data from the inertial measurement unit in the underwater vehicle at various known physical orientations to determine the relative alignment of the current meter and inertial measurement unit and quantify sensor biases of the flux gate compass and accelerometers. The ITP-V systems are now ready for deployment in support of future Navy research programs in the Arctic.

## **RESULTS**

Nothing to report. The ITP-V systems are now ready for deployment in support of future Navy research programs in the Arctic. Specifically, the plan is to use these systems in support of the Stratified Ocean Dynamics of the Arctic (SODA) DRI program.

## **IMPACT FOR SCIENCE**

Observations and insights deriving from ITP-V instruments are advancing understanding of ice-ocean interactions and their representation in numerical models. In turn, improved predictions and assessments of the future state of the Arctic Ocean will result.

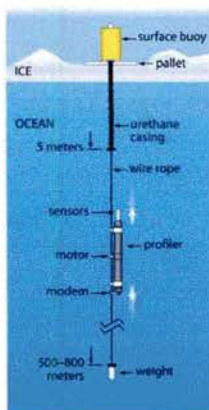
## **RELATIONSHIPS TO OTHER PROGRAMS**

The three ITP-V systems constructed under this funding are scheduled to be used during the ONR Stratified Ocean Dynamics of the Arctic (SODA) DRI program.

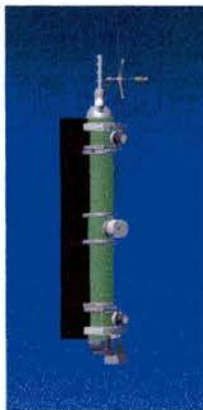
ITP-V systems were previously used in the Marginal Ice Zone DRI study:  
<http://www.apl.washington.edu/project/project.php?id=miz>  
and in a follow-on research study entitled "Upper-Ocean Variability in the Arctic's Amundsen and Nansen Basins," Grant N00014-15-1-2547.

**EQUIPMENT LIST: 3 ITP-V Systems – Completed and ready for use.**

## FIGURES/PICTURES



**Figure 1. Schematic drawing of the Ice-Tethered Profiler instrument system.**



**Figure 2. Engineering drawing of the Ice-Tethered profiler with Velocity.**

**Figure 3. Right. Photograph of an MIZ ITP-V being deployed (top) and in a test jig used to validate sensor orientations (bottom).**



## REFERENCES

- Cole, S. T., M.-L. Timmermans, J. M. Toole, R. A. Krishfield, and F. T. Thwaites, 2014: Ekman veering, internal waves, and turbulence observed under Arctic sea ice, *J. Phys. Oceanogr.*, 44, 1306-1328.
- Cole, S. T., F. T. Thwaites, R. A. Krishfield and J. M. Toole, 2015: Processing of velocity observations from Ice-Tethered Profilers, MTS/IEEE Oceans' 2015, Washington DC, 1-10.
- Krishfield, R., J. Toole, A. Proshutinsky, and M.-L. Timmermans, 2008: Automated Ice-tethered Profilers for seawater observations under pack ice in all seasons. *J. Atmos. Oceanic Technol.*, 25, 2091-2105.
- Thwaites, F. T., and R. Krishfield, 2013: Development of a second-generation Ice Tethered Profiler with velocity sensor, Proc. Oceans 2013 San Diego Conference, San Diego, CA, IEEE Xplore.
- Toole, J. M., R. A. Krishfield, M.-L. Timmermans, and A. Proshutinsky, 2011: The Ice-Tethered Profiler: Argo of the Arctic, *Oceanogr.*, 24, 126-135.